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A SURVEY OF TRUCK NOISE LEVELS AND THE EFFECT OF REGULATIONS

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WYLE LABORATORIES

REPORT

WYLE RESEARCH REPORT
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A SURVEY OF TRUCK NOISE LEVELS AND THE EFFECT OF REGULATIONS

By

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1.0 INTRODUCTORY SUMMARY

It has long been recognized that heavy trucks are one of the major sources of noise in our society, and certainly the major source of noise from the urban and rural highways on which they operate. This recognition has led to the development of several state regulations incorporating noise standards for this and other classes of vehicles. As time goes on, it is expected that an increasing number of states will introduce their own noise regulations, each one directed towards the solution of local problems and of a severity determined by local pressures. It is fairly clear that there will be discrepancies between these various regulations, the result being that vehicles engaged in interstate commerce would be subject to a variety of different noise standards for the same operation in different areas of the country. This situation clearly would create an impediment to commerce that could not be tolerated.

The majority of heavy trucks operating on the highway either cross state lines or are transporting goods that cross state lines, and so can be considered to be engaged in interstate commerce. As such they are subject to federal regulations, which, if applied to noise emissions, would succeed not only in reducing the noise impact for communities close to heavily traveled highways, but also in utilizing the power of federal preemption to provide a consistent set of noise standards throughout the nation.

The mandate for federal action was provided in Section 18 of the Noise Control Act of 1972 which required the Environmental Protection Agency to develop regulations governing the noise emission of motor carriers engaged in interstate commerce. The first step in the development of the regulations by EPA was a definition of the noise characteristics of heavy trucks as they operate on the highway. This information was required to provide baseline data for the existing fleet of trucks and to indicate the modes of operation for which noise regulations would be most applicable. Accordingly, a measurement survey was conducted to sample truck noise levels in different parts of the country under different operating conditions, the results of which would also indicate the effectiveness of certain existing state regulations.

A survey methodology was developed and used in a measurement series designed to sample the noise levels produced by trucks operating on the highway. A total of 7449 trucks were monitored at 25 locations in speed zones of less than and greater than 35 mph. Included in the monitoring was the effect of road grade, truck size, and the type of surface between the vehicle and the measuring microphone. In all cases, the measurements were taken with the microphone 50 feet from the center of the lane in which the vehicle was traveling.

The results of the measurement series were used first to characterize the noise levels produced by the nation's existing fleet of trucks. It was determined, for example, that about 25 percent of the 5-axle trucks operating on the highways exceed 86 dBA at low speeds and about 40 percent exceed 90 dBA at high speeds – these levels representing the California noise standards when measured over a grass surface at the roadside. When the measurements are conducted over a hard surface such as concrete, these percentages increase to about 48 percent and 67 percent, respectively. In addition, the following conclusions were drawn:

- the method of measuring low speed truck noise levels as they accelerate past a single microphone leads to results that can be as much as 5 dB conservative on the low side
- the stationary run-up test procedure appears to be the most acceptable field procedure for characterizing the maximum noise levels produced by trucks operating at low speeds with an excellent repeatability
- the mean difference between noise level measurements taken over concrete and grass surfaces is 2 dB – a factor that should be included in enforcement
- the effect of the application and enforcement of noise regulations in California has resulted in a reduction in truck noise levels for both low and high speed operation

- an effect termed "regulation by influence" is observed in which noise regulations in one state affect typical truck noise levels in neighboring states.

The remainder of this report contains a detailed description of the measurement survey, and the rationale for its development, together with a discussion and evaluation of the measured data.

2.0 DEVELOPMENT OF MEASUREMENT SURVEY

The noise produced by a truck on the highway is a function of its mode of operation, and so the first step in the development of a noise regulation is the definition of the mode or modes of operation for which the corresponding truck noise presents a potential community problem and hence should be limited. This requires a knowledge of the typical truck duty cycle together with the noise levels produced by the truck in each part of the cycle. With this information, a method for measuring the noise emission from a truck can be established, so that the measured values relate to those exhibited during specific operations on the highway. The selected method can then be used to establish a data base of existing truck noise levels.

2.1 Truck Noise Parameters

It is convenient to consider truck noise as being produced by two major, mutually independent sources – namely, the propulsion system and the tires. The propulsion system in this context is considered to include the engine, exhaust, intake, fan, and other auxiliary equipment in the engine compartment. The noise level produced by the propulsion system is dependent on the engine speed for the operation of the truck in each gear. The relationship is illustrated in Figure 1 (a), which shows the relationship between the noise level and the engine rpm with the vehicle speed as parameter. The relationship can be considered to be essentially universal for a given truck at all vehicle speeds. The overall range of the noise level throughout the acceleration in a given gear can be 20 dB or more, but under typical road conditions the range will be much less than this – more on the order of 10 dB. The maximum noise level in each case is associated with maximum engine rpm. The slight increase in noise levels at 48 mph over those at 8 mph shown in Figure 1 (b) is the result of the increased contribution from the tires.

Another way of looking at this is illustrated in Figure 1 (b), which indicates the variation in the noise level produced by an accelerating vehicle as a function of vehicle speed. It can be seen that there is no relationship between the noise level

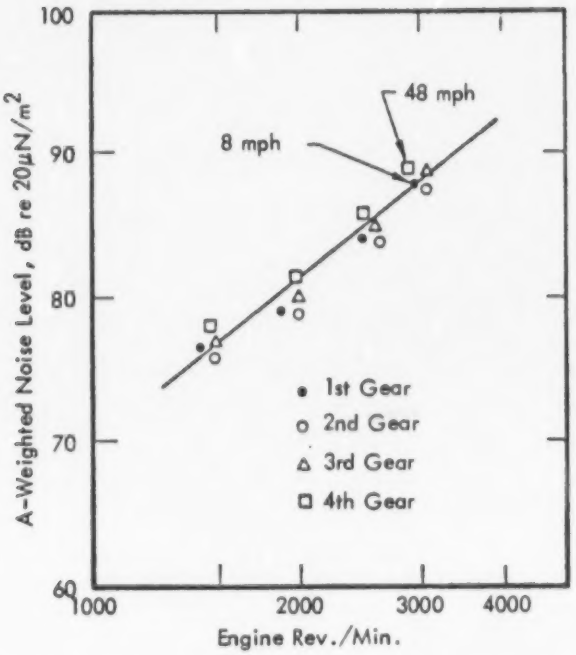

Figure 1(a). Diesel Truck Noise as a Function of Vehicle Engine rpm* (Reference 1)

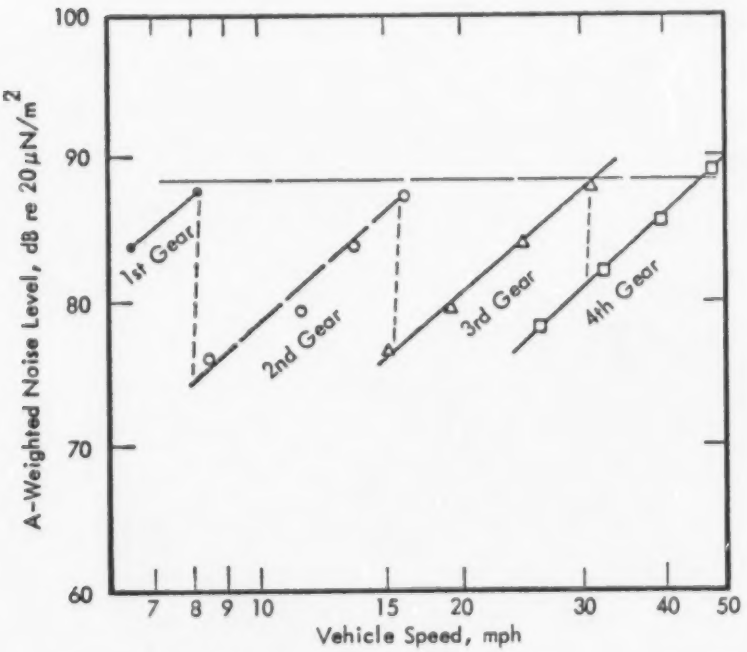

Figure 1(b). Diesel Truck Noise Level as a Function of Vehicle Speed* (Reference 1)

*Microphone 7.5 Meters (25 Feet) from Centerline of Vehicle's Path.

and the vehicle speed except indirectly via the gear ratio, with the result that the noise level produced by the propulsion system is effectively independent of the vehicle speed.

The noise from the tires is the result of the interaction of the tires with the road surface and is due to a combination of carcass vibration and the entrapment and subsequent release of air from the tread cavities. The noise levels are therefore related in some way to the vehicle speed. The rate of increase of the noise level with vehicle speed is approximately the same for most types and designs of tire, and is on the order of 10 to 12 dB per doubling of speed.[2]

Since the maximum noise from the propulsion system is constant with vehicle speed, but tire noise increases with vehicle speed, there will be a speed above which the tire noise becomes predominant. The absolute noise level produced by the tires at any given speed is a function of the tire construction, so this critical speed will vary from truck to truck according to the type and mix of tires installed. It will also vary with the number of tires on the vehicle, including the trailer. Generally speaking, however, the critical speed is greater than about 40 mph, so that at lower speeds the overall truck noise is dominated by the contribution from the propulsion system.

In addition to parameters such as road and engine speed, the noise produced by a truck is also dependent on the rated load it is designated to haul. Clearly, a truck designed to haul large loads requires a more powerful engine than one designed for smaller loads, if it is to maintain flexibility in its operation on the highway. There is no exact relationship between maximum engine horsepower and the associated noise level because of the complex relationship of both quantities with the engine size and the engine speed, and the effects of adding turbochargers, etc. It is sometimes possible, for example, for more powerful engines to produce less noise than their less powerful counterparts. In the case of existing trucks, the noise levels are also dependent to some extent on the degree of maintenance – particularly with regard to the exhaust system – which furthers blurs the relationship with horsepower. On the other hand,

there is a general changeover from the quieter gasoline to the noisier diesel power units with increasing load-carrying capability, so that the overall effect is a trend towards higher noise levels with higher rated loads.

For a given truck, the effect of different payloads on the noise produced depends upon the mode of operation. Under full acceleration, the engine is working under load and an increase in the payload will simply lengthen the time taken for the truck to reach a given road speed, but will not sensibly affect the maximum noise level produced. At a constant speed on a level road, the noise level will vary slightly with payload, because the load on the engine under this condition is provided to a large extent by the rolling resistance which depends upon the axle loading. The only condition where a major change in noise level might be expected due to an increase in payload is on a grade where an increased torque is required to counteract the increased component of the truck weight. However, it is usual for truck drivers to operate at maximum horsepower, i.e., at the rated engine speed, whenever possible, so that an increase in payload will normally result in a lower vehicle speed and not necessarily a higher noise level. This typical driving characteristic thus significantly reduces the effect of payload on truck noise levels.

2.2 Measurement Procedures

The discussion of the previous section has shown that the noise level produced by trucks varies considerably with the mode of operation. The question thus arises as to which mode of operation should be selected for the measurement of truck noise emissions. Since the propulsion system noise dominates at low vehicle speeds and the tire noise often dominates at high vehicle speeds, it would seem reasonable to characterize these two major sources by measurements in the two respective speed ranges. The existing recommended test method for measuring the noise produced by trucks, namely SAE J 366b,[3] is designed to extract the maximum noise from a truck without considering the problems of tire noise. Accordingly, the test is conducted at high engine speed and fairly low vehicle speed. The noise levels measured in this way represent about

the maximum that can be produced by the propulsion system and are typical of those produced at maximum engine speed under urban driving conditions. It is important to remember that a truck is normally operated at maximum engine speed. This is the test procedure used by the truck manufacturer to ensure that the new vehicles comply with specific noise standards, such as those contained in the California noise regulations.

The corresponding test for measuring tire noise (SAE XJ57) is tentative and at present under review and involves a vehicle coast-by at 55 mph past the microphone. As proposed, the test is designed to measure the noise levels produced by a set of tires mounted on the drive axle of a truck tractor. However, the test can equally well be conducted with any combination of tires, including trailer tires, as used on the highway. The noise levels measured by this method and by J 366b are sufficient to define the noise level produced by a truck traveling at any speed provided that the truck is operated under load at a high engine speed. Lower noise levels may be produced while cruising at low speeds where the engine load or speed is below maximum.

The SAE J 366b test procedure is now accepted by manufacturers and legislators to be the best available method for measuring maximum noise emissions. It does have the disadvantage that it cannot practically be used for enforcing noise regulations on the highway. As a result, the enforcement of vehicle noise regulations has been traditionally conducted by monitoring the noise produced by vehicles in the course of their normal operation on the highway. For the enforcement of low speed noise standards – which are effectively standards for the noise produced by the propulsion system – measurement locations are selected to monitor accelerating trucks, and so the noise levels measured can approach the maximum as measured by the SAE J 366b procedure. However, depending upon the gear shift pattern for the particular truck under test, the noise level measured by a single microphone may be significantly less than the maximum (see Section 2.3).

Recently, an alternative test procedure has been developed[4] that enables the maximum noise from the propulsion system to be measured with the truck in a stationary position. The so-called stationary run-up test involves a rapid acceleration of the

engine followed by a short period of equilibrium at the governed engine speed and a rapid deceleration back to the idle condition. The operation is, of course, conducted in neutral gear and the load on the engine provided by the fly-wheel is sufficient to obtain approximately the maximum noise level. Tests conducted by the motor vehicle manufacturers have shown a good correlation between the noise level measured in this way and that according to the more standard SAE method.[5] It is, of course, only possible to conduct this type of test on trucks equipped with engine speed governors.

2.3 Relationship Between Measurement Procedures

In the discussion of the previous section, it appeared that there are basically two methods for measuring the noise produced by trucks that are suitable for enforcement purposes. These are the stationary run-up test and the pass-by measurement. Each has its own special application and a regulation can be usefully stated in terms of both, provided that they are mutually compatible. To determine the relationship between the two measurement procedures, a series of tests were conducted at a weigh station on Interstate 66 in Virginia, 25 miles west of Washington, D.C. Westbound trucks using the exit lane to the weigh station were stopped before the scales and the drivers asked to perform the stationary test procedure at least four times. The person assigned to explain the procedure to the drivers monitored the operation of the throttle to ensure that it was wide open during the acceleration. This is required so as to obtain the maximum noise level which correlates well with the maximum level produced during the SAE J 366b test procedure. In addition to the stationary tests, measurements were also taken of the noise produced by each truck as it accelerated away from the scales. During this operation, the noise level varies with position along the roadway as the driver shifts through the gears, and so as mentioned earlier, a single microphone placed alongside the vehicle path may not measure the maximum noise level produced by the vehicle. To overcome this problem and increase the probability of measuring the maximum noise level, three microphones were placed 25 feet apart, 50 feet from the center of the lane in which the vehicle was traveling, the first microphone being 45 feet from the vehicle starting point on the scales.

For the stationary test a location was selected with a hard ground surface – concrete – between the microphone and the vehicle under test. This is a required condition for a good correlation to exist between the noise levels measured during this test and those from the SAE J 366b test which is also conducted over a similar hard surface. On the other hand, for the low speed pass-by measurements, a location was selected with a grass surface between the microphone and the vehicle to simulate a roadside measurement site at which the majority of roadside noise measurements to be discussed in the next chapter were conducted. Previous results based on only a small sample of data showed that the effect of the change from a concrete to a grass surface would result in a decrease in noise level of about 2 dB.

The vehicles tested were a mixture of 3-, 4- and 5-axle trucks, the majority of which were powered by diesel engines. In order to avoid congestion on the incoming lane to the weigh station, it was not possible to stop every vehicle for the purposes of the test. For this reason, the stationary test series was limited to only 60 trucks before the onset of heavy wind gusts approaching 12 mph made further measurements impossible. The sample size obtained in these measurements was clearly too small to draw any conclusive evidence as to the numbers of vehicles that do not comply with specific noise standards although it is sufficient to examine trends in the data.

The stationary run-up test was performed four times by the majority of trucks participating in the measurements. In many cases the first attempt by the driver did not produce the rapid acceleration necessary for the test. Accordingly, the average of the three highest noise levels obtained from the four tests was used to characterize the stationary run-up test level. Of the 60 trucks measured, 21, or 35 percent, exceeded a noise level of 88 dBA. Within the small sample involved, the repeatability of the three highest levels was considered excellent, with 93 percent of the trucks exhibiting a total spread of 1 dB or less. The mean spread was 0.7 dB with a standard deviation of 0.4 dB.

Measurements of the low speed pass-by noise level produced by each of the 60 trucks at the three microphone locations showed that the percentages exceeding a noise level of 86 dBA, (2 dB lower than 88 dBA because of the grass surface and therefore

equivalent in severity to the 88 dBA stationary run-up test), were 25 percent, 28 percent and 24 percent at microphone locations #1, #2, and #3, respectively. Taking the maximum noise level measured at any of the three microphone locations, the percentage exceeding 86 dBA increased to 30 percent. The spread in noise levels between the three microphones for any given truck ranged from 0 to 5 dB, with a mean value of 1.5 dB and a standard deviation of 1 dB. The difference between the noise level distributions measured by means of the two test procedures is shown in Figure 2. The mean difference (accounting for the difference in ground surface) is 1.6 dB with a standard deviation of 2.4 dB.

Three main conclusions can be drawn from the results of the limited series of measurements. First, it appears that the repeatability of the stationary run-up test is good, provided that an observer is present to witness the operation and ensure that the engine acceleration is rapid. Trial runs may be required in some cases.

Second, the noise level from an accelerating truck as measured by means of a single stationary microphone does not necessarily represent the maximum noise level produced by the truck during this operation. If the measurement is repeated for a large number of trucks, then the absolute number measured with noise levels exceeding a standard will not vary significantly with microphone location, but the population exceeding the standard will not be exactly the same for each location. The microphone location with respect to the point where the truck produces maximum noise is not too important a factor in the enforcement of noise standards if the noise level exhibited is greatly in excess of the noise standard. The location is a factor, however, in the case of a truck which exhibits a maximum noise level close to the noise standard.

Third, the number of vehicles measured as being out of compliance with noise standards is likely to be greater for the stationary run-up test than for the passby test. This follows from the previous statement because the noise level measured according to the stationary test procedure represents the maximum level that can be produced by the vehicle and is not a function of vehicle operation.

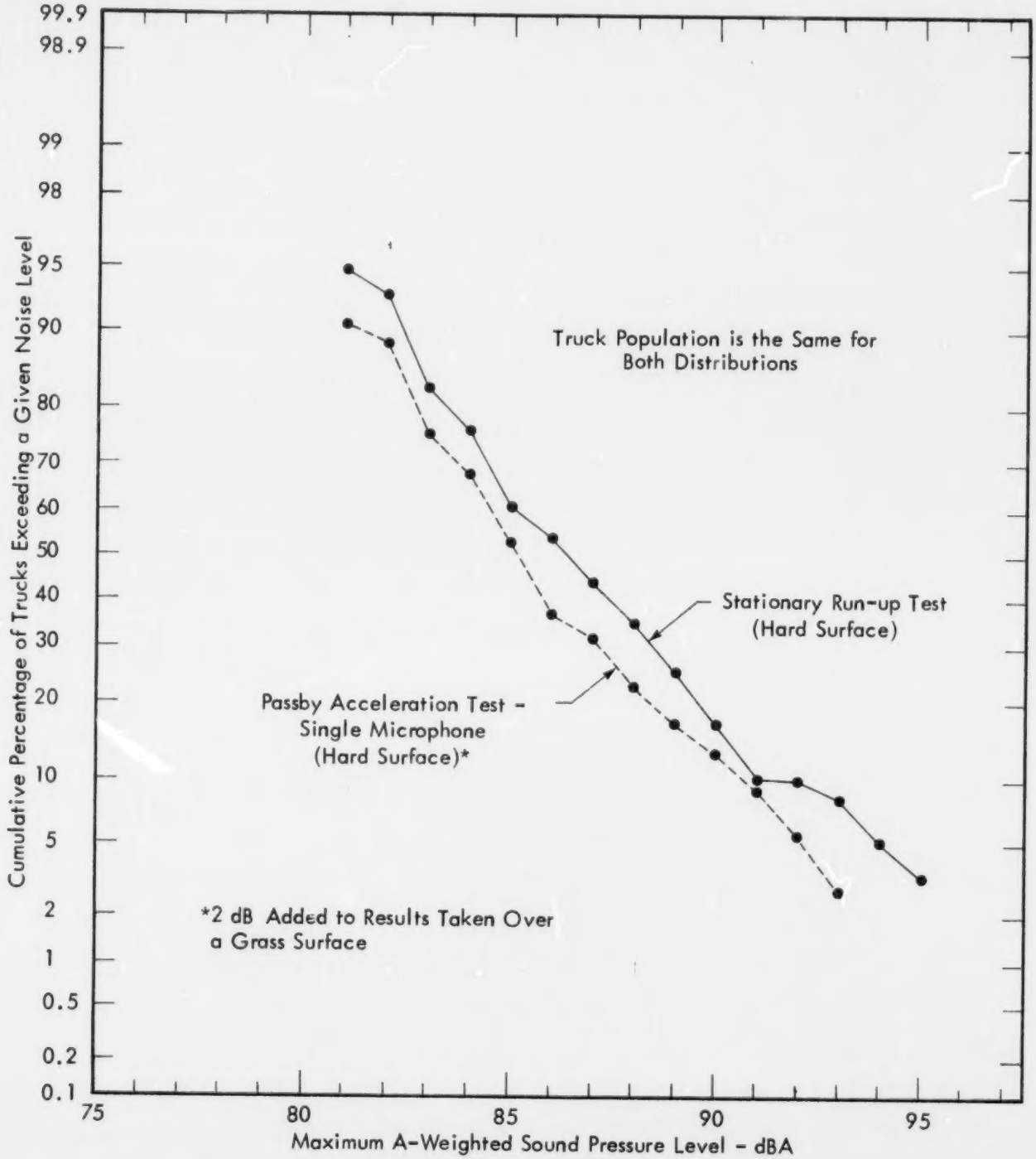

Figure 2. Truck Noise Levels as Measured by Passby Acceleration Test and Stationary Run-up Test

Thus, the stationary test indicates whether or not a vehicle actually complies with the noise standard; the pass-by test with a single microphone is more conservative and will register fewer violators, merely because it relies on a certain probability of measuring the maximum noise level. It is important to note that as the number of measurement microphones increases, the percentage of violators measured according to the pass-by test approaches that indicated by the stationary test procedure.

2.4 Definition of Survey Methodology

The discussions of the previous sections indicate that truck noise can be reduced by controlling the noise emissions from the propulsion system and the tires.* The propulsion system noise can be controlled by regulating the emissions at low road speed, and since trucks typically operate at high engine speeds with corresponding high noise levels, it is reasonable to apply the regulation to the maximum levels produced. These levels can only be determined precisely by means of the J 366b or stationary run-up test procedures which are difficult and time consuming to conduct. Approximations to the maximum levels can be obtained by measuring the noise from trucks operating under acceleration on the highway, but these will normally be conservative on the low side. However, they do represent real conditions to be experienced alongside highways, and so accordingly, the method of measuring pass-by noise levels was adopted for the survey.

Because of the dependency of the noise level on the engine speed rather than the vehicle speed, it is not sufficient to state a standard speed at which the noise level shall be measured. Nor is it desirable, because it would severely limit the number of vehicles that could be measured under typical highway conditions. Furthermore, if the data base and hence the eventual regulation is specified in terms of a noise level at a given vehicle speed, subsequent enforcement of this regulation would require a measurement of the vehicle speed – something that would be undesirable. It is more convenient to adopt the approach taken by the State of California wherein the noise standard is stated as a function of speed zone as opposed to actual speed. Thus, the

*Provided, of course, that the technology exists at an acceptable cost.

measurements of the propulsion system noise were taken from vehicles accelerating within low speed zones, the most common of which restricts vehicle speeds to 35 mph or less. A speed limit greater than this might possibly result in the measurement of propulsion system and tire noise and accordingly was not considered.

To control the noise produced by the tires, it is necessary to establish a noise standard for high speed operation. At high speeds, the noise from a truck will be dependent on contributions from both the propulsion system and the tires; the latter contribution becoming stronger as the speed increases. Thus, the total noise level will be dependent not only on the type of tires installed on the vehicle but also on the relative noise contribution from the propulsion system. Both these quantities may vary considerably from vehicle to vehicle so that there will be no universal relationship between the overall noise level and the vehicle speed. This raises the question as to the conditions under which the high speed noise measurements should be taken.

A survey of vehicle speeds on interstate highways shows that the majority of trucks tend to travel within a fairly limited speed range – a typical average being in the order of 56 mph. Typically, about 70 percent of the trucks operate at speeds within $\pm$ 5 mph of this average, except when they encounter any significant grade.[6,7] This fairly consistent behavior means that noise levels may be measured from samples of vehicles operating on different highways without the need for strict monitoring of individual vehicle speeds on those highways. This, in fact, was the procedure adopted not only for convenience but also because it has been shown that the presence of a radar speed measuring device affects the free speed at which trucks operate. The measured results are therefore indicative of the range of noise levels to which the community is exposed. Throughout the measurements, spot checks were made of the vehicle speeds to ensure that they lay within the range mentioned above.

It was also desirable to categorize the trucks in some way according to their size. It is, of course, impossible to determine the weight rating of a truck as it passes on the highway, but since there is an approximate relationship between the number of axles on a truck and the rated load capacity, it was decided to categorize the trucks in terms of their number of axles.

3.0 TRUCK NOISE SURVEY

The survey methodology was used in a measurement series designed to sample the noise levels produced by trucks throughout the nation. A total of 7449 trucks were monitored at 25 locations in speed zones of less than and greater than 35 mph. Included in the monitoring was the effect of road grade, truck size, and the type of surface between the vehicle and the measuring microphone. Some of the measurements were conducted in states where noise regulations were being enforced, thus allowing an assessment of the effect of such regulations to be made. In all cases, the measurements were taken with the microphone 50 feet from the center of the lane in which the vehicle was traveling. The sites were selected so that the effect of reflections from nearby obstacles was less than 0.5 dB.[8] The measurements were conducted in the summer of 1973; the ambient temperature for the complete series was in the range of 75 to 85°F and the surface of the road was dry in all cases.

The maximum A-weighted noise level produced by each vehicle as it passed by the microphone was recorded with the convention of rounding down to the nearest integer. Thus, for example, all noise levels within the range 86.0 to 86.9 dBA were recorded at 86.0 dBA. Normal calibration procedures were adopted throughout the measurements with the sound level meter and its microphone being calibrated before and after each series of measurements and at two hourly intervals during the measurements.

The total number of vehicles measured are shown in Tables 1 and 2 according to the number of axles and the measurement location. It can be seen that, with the exception of Florida, the percentage of each axle type is fairly consistent from state to state. It is to be noted that these percentages refer only to the trucks that passed by the microphone during the measurements. They are thus representative of the typical percentages to be found on a major highway, but are not representative of the national percentages of vehicles within each class.

Table 1

Trucks Included in the Low Speed Measurement Series
According to Number of Axles and Site Location

Speed Zone < 35 mph

State	Number of Axles				Total
	2	3	4	5	
California	117	66	12	146	341
Colorado	50	24	15	183	272
Florida	130	44	165	44	383
Maryland	--	23	27	142	192
Missouri	66	32	15	304	417
New York	42	45	9	103	199
Texas	68	45	28	159	300
Virginia	--	52	52	203	307
Total	473	331	323	1284	2411
Relative Percentage *	22%	14%	5%	60%	100%

* Rounded to the nearest integer, excluding Florida, Maryland and Virginia.

Table 2

Trucks Included in the High Speed Measurement Series
According to Number of Axles and Site Location

Speed Zone > 35 mph

State	Number of Axles				Total
	2	3	4	5	
California	250	100	77	1444	1871
Florida	146	52	337	115	650
Illinois	48	36	34	455	573
New York*	171	58	80	281	590
Pennsylvania*	159	91	120	465	835
Texas	35	17	26	91	169
Virginia	--	27	74	249	350
Total	809	381	748	3100	5038
Relative Percentage**	16%	8%	8%	68%	-

* Includes flat and grade freeway.

** Rounded to the nearest integer, excluding Florida and Virginia.

3.1 Survey Results

The first intent of the survey was to study the relationship between the noise level and the vehicle weight rating, or in this case the number of axles, for trucks not presently influenced by noise regulations. The cumulative distributions of the noise level for 2-, 3-, 4-, and 5-axle trucks traveling at low speed, with the measurements conducted over a grass surface, are shown in Figure 3. As would be expected, the noise level is proportional in some way to the number of axles; 3-axle trucks being approximately 5 dB noisier than 2-axle trucks, and the difference between 3- and 4- and 4- and 5-axle trucks being in the order of 1 dB. The relatively low noise levels for 2-axle trucks are largely the result of the predominance of gasoline power units. It is perhaps to be expected that the distributions for 4- and 5-axle trucks would be similar because in many cases the tractor may contain the same or similar power unit. This explains the anomalous behavior of the two distributions at the higher noise levels. The distributions for each axle classification exhibit essentially the same general slope, which means that the standard deviation, or spread of noise levels, is the same in each case. This similarity appears to be characteristic of the distribution of truck noise levels, as will be seen from the results to be presented later in this section.

Similar results for the noise level produced by 2-, 3-, 4-, and 5-axle trucks traveling at speeds in excess of 35 mph are shown in Figure 4. These data are taken from trucks traveling on freeways where the average speed is in the order of 57 mph with a standard deviation of approximately 5 mph. The first point to be noticed is that the curves are much smoother than in the corresponding low speed case. Here, however, the spacing between the distributions for the 2-axle and the other classes is less because the differences are now largely due to differences in the tire noise contribution rather than that from the propulsion system. Because of the difference in the number of tires, the spacing between the distributions for the 4- and 5-axle trucks is greater than before. Taking the number of tires on the axles of the 2-, 3-, 4-, and 5-axle trucks, excluding those on the steering axle, the distributions follow fairly closely a 3 dB per doubling of tire characteristic.

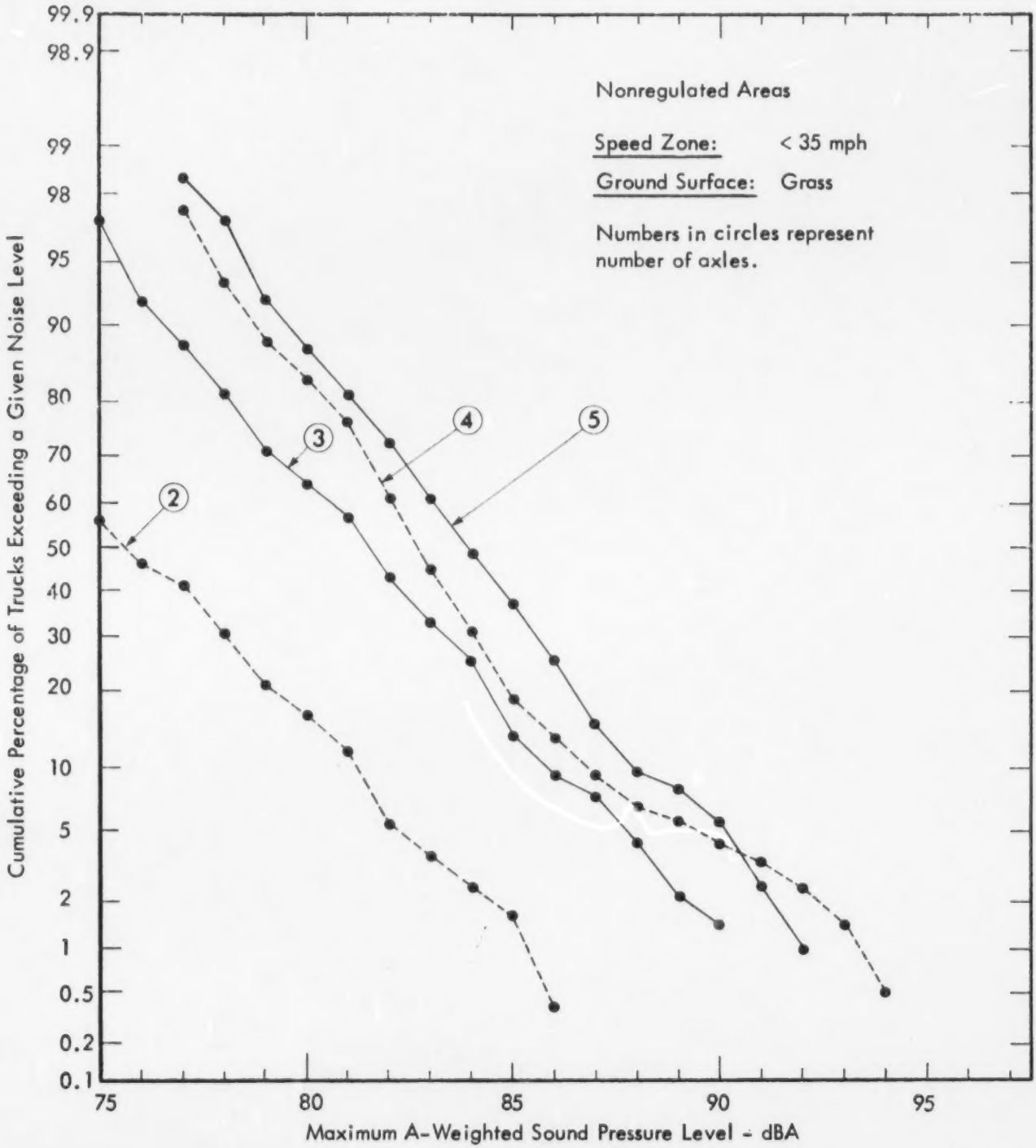

Figure 3. Noise Level Distributions for Trucks Accelerating in Speed Zones Less Than 35 mph in Nonregulated Areas.

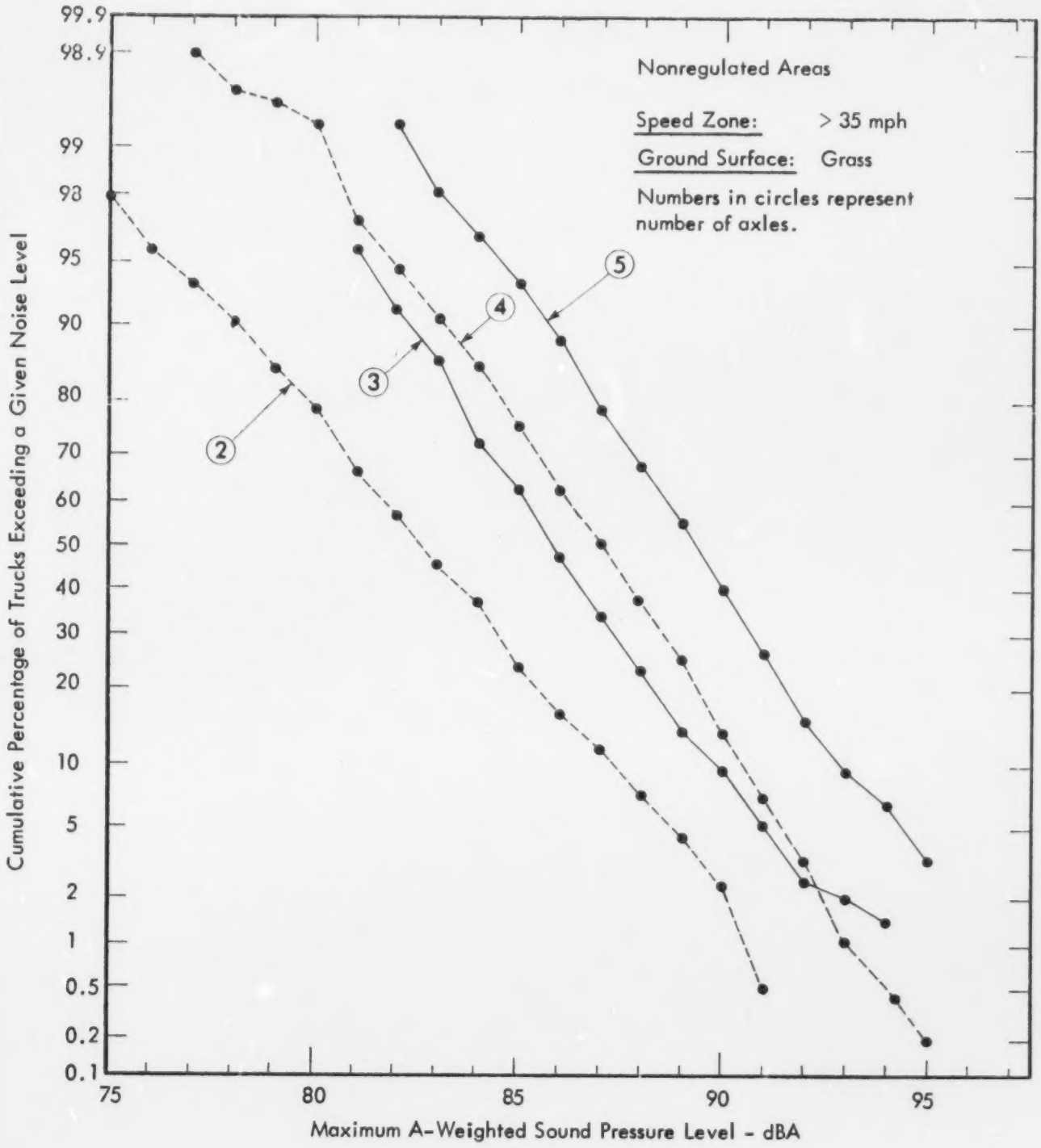

Figure 4. Noise Level Distributions for Trucks Operating in Speed Zones Greater Than 35 mph in Nonregulated Areas.

Figure 5 compares the distributions for high and low speed truck noise levels as measured in states far removed from those with regulations that are under active enforcement. There is a consistent difference of approximately 5 dB between the two distributions. This difference is not all due to the contribution from the tires because it will be remembered from the discussion in Chapter 2 that the noise levels measured at low speed under acceleration are not necessarily the maximum levels that the trucks are capable of producing. The difference between this measured value and the maximum value is 1.6 dB on average, so the conclusion can be drawn that the average difference in the distributions due to the effect of the tires is approximately 3.4 dB, assuming that the high speed trucks were operating near maximum power.

The effect of grade upon the noise levels produced by trucks traveling at high speed is shown in Figure 6. It is a common misconception that motor vehicle noise regulations can be enforced most effectively on freeway grades where it is assumed the trucks will be producing maximum noise. Figure 6 shows that this is not true, as might be expected upon close examination. A truck will generally operate at a lower speed on a grade than it will on a level highway, hence the noise contribution from the tires will be correspondingly less, although that from the propulsion system may be the same or even slightly greater. The net result is a decrease in the noise level. The amount of the decrease will depend upon the steepness of the grade and the portion of the grade at which the measurements are conducted. For example, in the center of a long, steep grade it would be expected that the reduction in noise level over that produced on a flat freeway would be maximum. On the other hand, at the start and at the end of the grade the reduction would be correspondingly less. In Figure 6 the reduction is on the order of 2 dB. Similar measurements on steeper grades have shown differences of as much as 3 dB. It is interesting to note in Figure 6 that the distributions merge at the higher noise levels. Since the two distributions are for the same sample of trucks, this presumably indicates that the noise from the noisiest trucks is produced predominately by the propulsion system – probably the exhaust system – which, of course, is unaffected by vehicle speed. Since the trucks in the sample measured were climbing the grade, it can be assumed that they were operating at or near

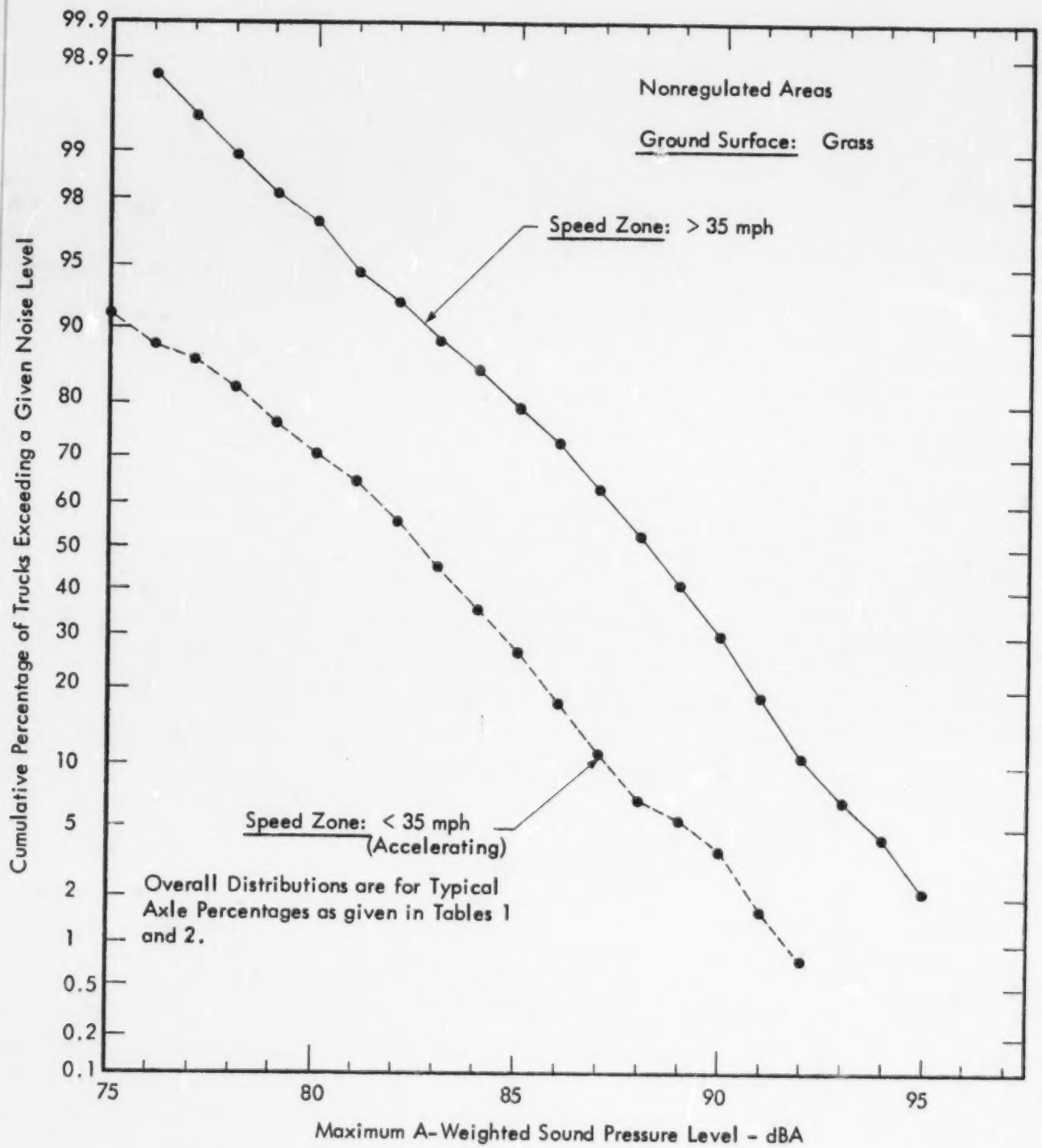

Figure 5. Overall Noise Level Distributions for Trucks Operating in Low and High Speed Zones in Nonregulated Areas.

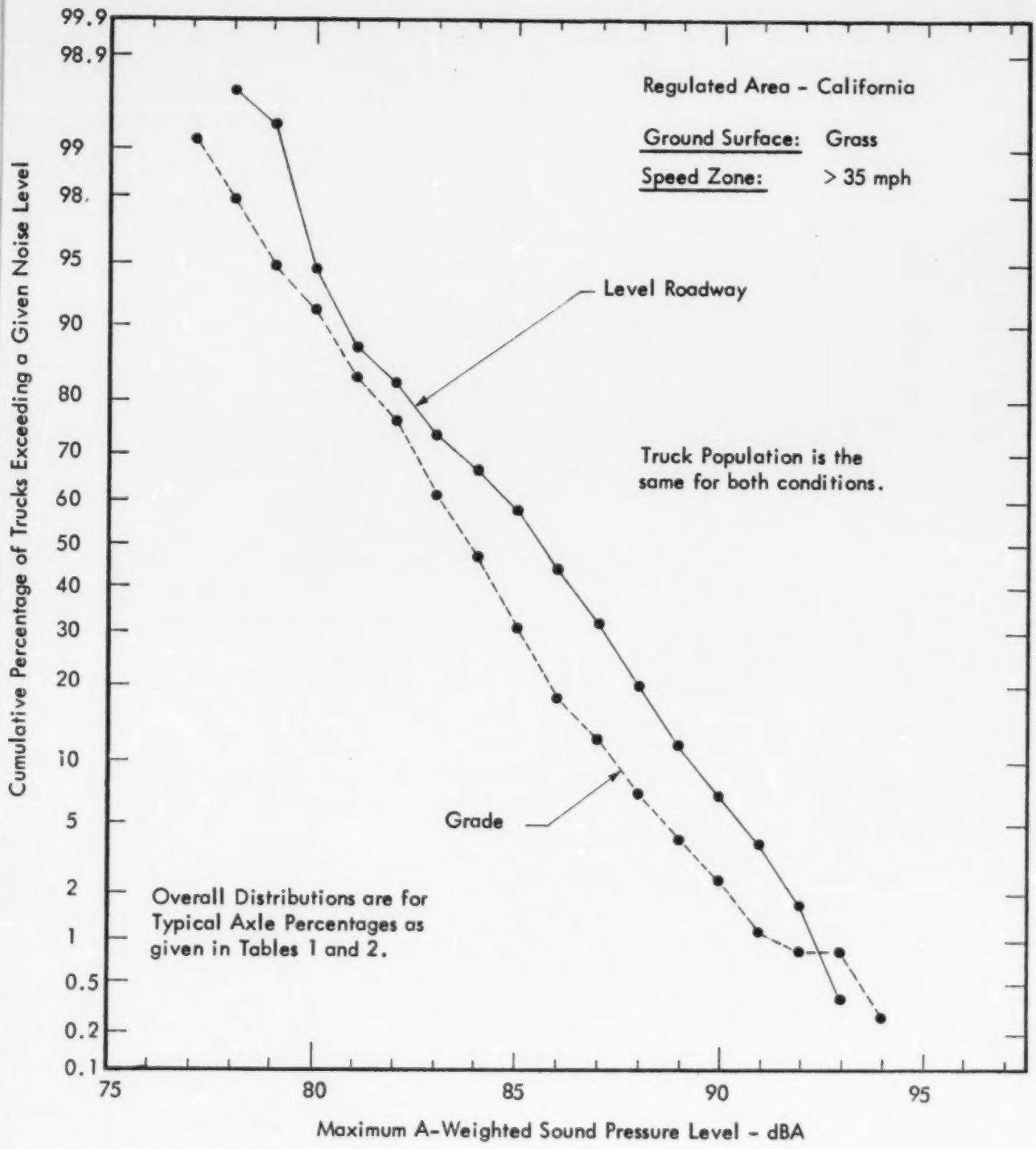

Figure 6. Overall Noise Level Distributions for Trucks Operating in Speed Zones > 35 mph on Level Roadway and on a Grade.

maximum engine speed. Thus, the noise levels from the propulsion system will be about the maximum it is possible to produce and will be generally higher than those measured under acceleration during a pass-by. Also, since the vehicle speed is significantly reduced on a grade, the major noise source will most likely be the propulsion system. It therefore represents a location where a fairly accurate measure of maximum propulsion system noise can be measured. Note that in both Figures 5 and 6 the distributions have been calculated for the overall truck flow using the typical percentages of different axle classifications as given in Tables 1 and 2.

The effect of the ground surface between the measurement microphone and the vehicle is shown in Figure 7. The distributions shown in this figure are for a different population of vehicles measured at different locations, but all were accelerating at low speed. The top distribution is for truck noise levels measured over a hard surface, such as concrete or sealed asphalt; whereas the lower distribution is for truck noise levels measured over a grass surface. Each distribution is the average of three individual series of measurements at three different locations. The height of the grass was typically 6 inches and the ground surface was firm but not dry and cracked. The difference between the two distributions on average is approximately 2 dB, this being due to the lower reflection coefficient for the sound path reflected from the grass surface. This indicates quite clearly the necessity to specify the ground surface in any subsequent noise regulation. Since the two distributions are for different truck populations, it cannot be stated that for a given truck the difference between the noise levels as measured over the two surfaces will be 2 dB; however, it should average 2 dB.

3.2 The Effect of Noise Regulations

One of the purposes of the truck noise survey was to examine the effectiveness of noise regulations introduced at the state level. A number of states do have such noise regulations, the best known, of course, being California which first introduced them in 1968. Unfortunately, there are little data on the noise levels from trucks operating in California prior to the introduction of the regulation. That which does exist was taken

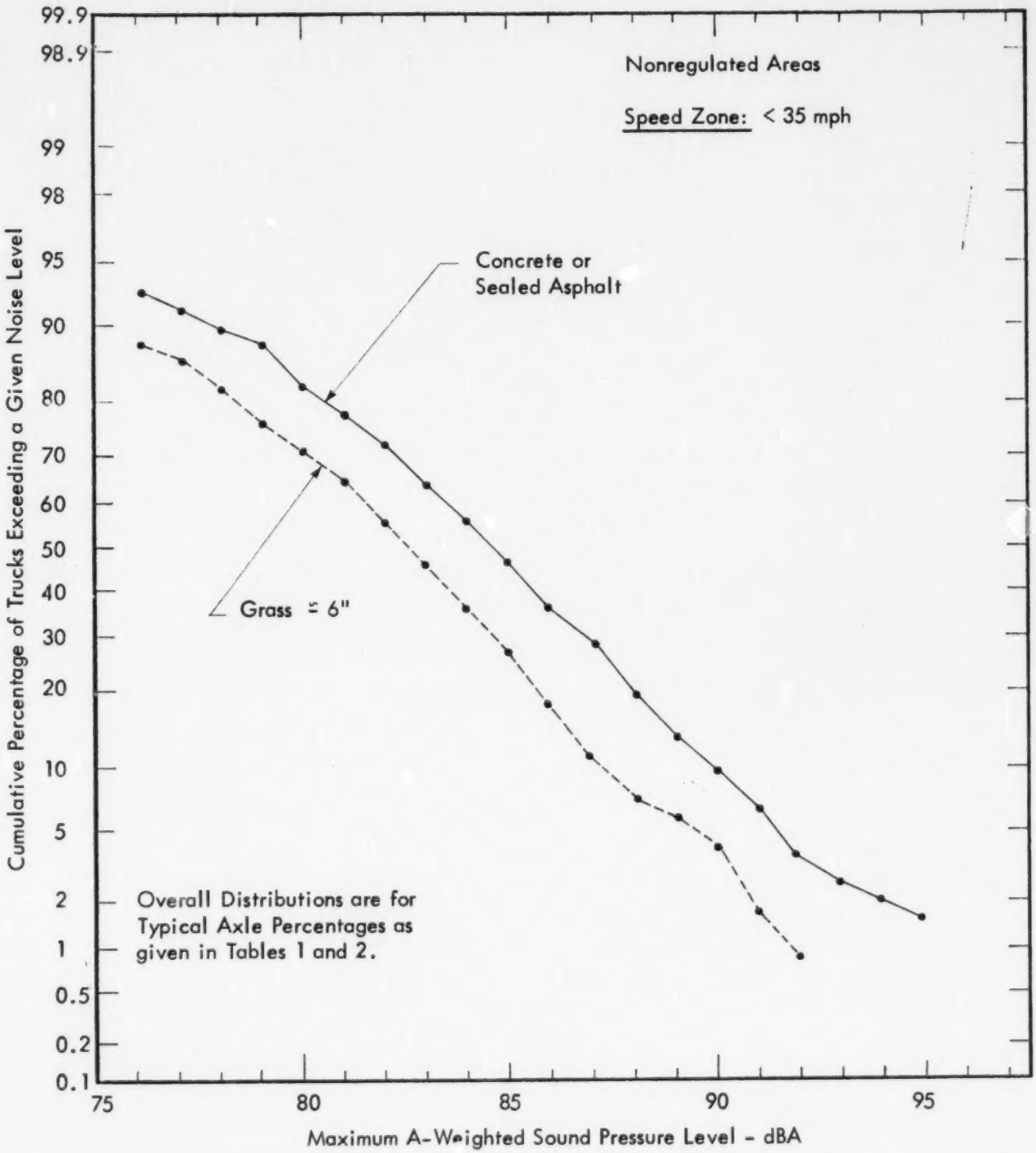

Figure 7. Overall Noise Level Distribution for Trucks Accelerating in Speed Zones < 35 mph With Ground Surface as Parameter.

by the California Highway Patrol in 1965 from diesel trucks operating at high speed on the open highway.[9] These measurements were taken at a distance of 25 feet from the center of the lane in which the vehicle was traveling, and so a correction factor is required to correct the values back to the more normal standard of 50 feet. A suitable correction factor would appear to be 4 to 5 dB.[8,10] In addition, the measurements were taken with a hard ground surface between the microphone and the vehicle. To account for both factors, namely, distance and ground surface, a 6 dB correction factor has been subtracted from the levels as measured in 1965 and the corresponding distribution of noise levels is shown in Figure 8. These original data do not contain information on the percentage of trucks in each axle classification and so it can only be assumed that the relative percentages are the same as those considered typical in Table 2. Under this assumption, the distribution of noise levels from trucks as measured in 1965 in the the State of California before the introduction of regulations is shown in Figure 8 to be very similar to the distribution of levels as measured in 1973 from trucks in states without regulations. This agreement tends to indicate that the typical noise levels produced by trucks have not changed significantly over the years in the absence of regulations. It is therefore possible to examine what has happened in the State of California since 1965 and extrapolate the results to determine the effect if similar noise standards were imposed upon trucks throughout the nation.

The effect of subsequent regulations in California between the years 1965 and 1973 – see Table 3 –is shown in Figure 9. The data representing the distribution as measured in 1973 are presented according to a typical distribution amongst axle types as given in Table 2. The intermediate curve represents the noise levels from trucks measured by the California Highway Patrol in 1971.[11] The original data from which this curve was produced were given only in terms of single and combination trucks. In the development of the 1971 distribution, it has been assumed that the term "combination truck" means trucks with four or five axles and that a single vehicle contains just two axles. The percentages have then been calculated from Table 2 with

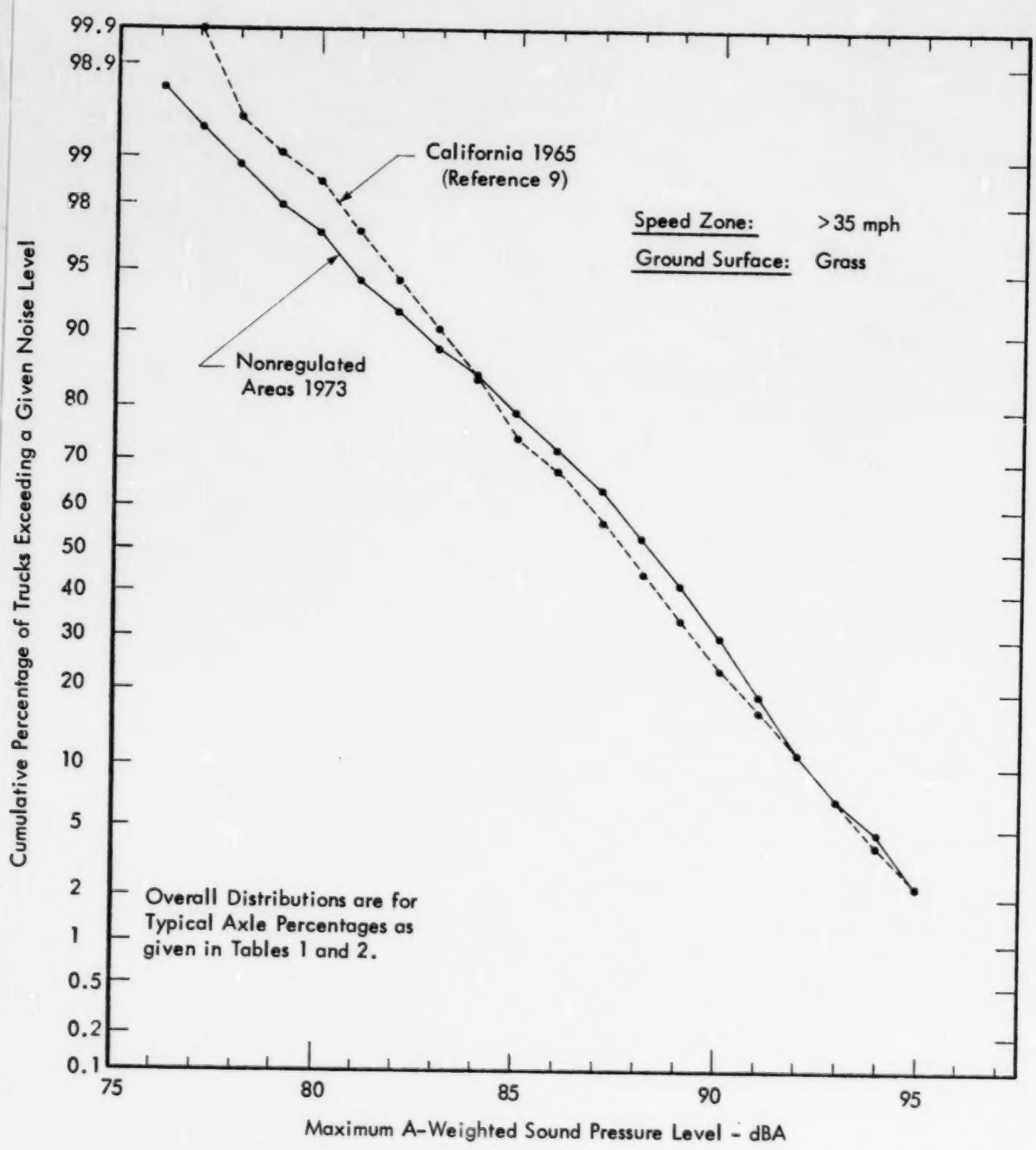

Figure 8. Overall Noise Level Distributions for Trucks Operating in Speed Zones > 35 mph in California in 1965 and in Nonregulated Areas in 1973

Table 3

Timetable for Truck Noise Regulations in California

Date	Noise Standard - dBA (Not to Exceed)		
	New Vehicles*	In Operation	
		≤ 35 Miles Per Hour	> 35 Miles Per Hour
January 1968	88	88	92
January 1970	-	-	90
January 1973	86	86	90

*Measured according to a test procedure equivalent to SAE J 366b.

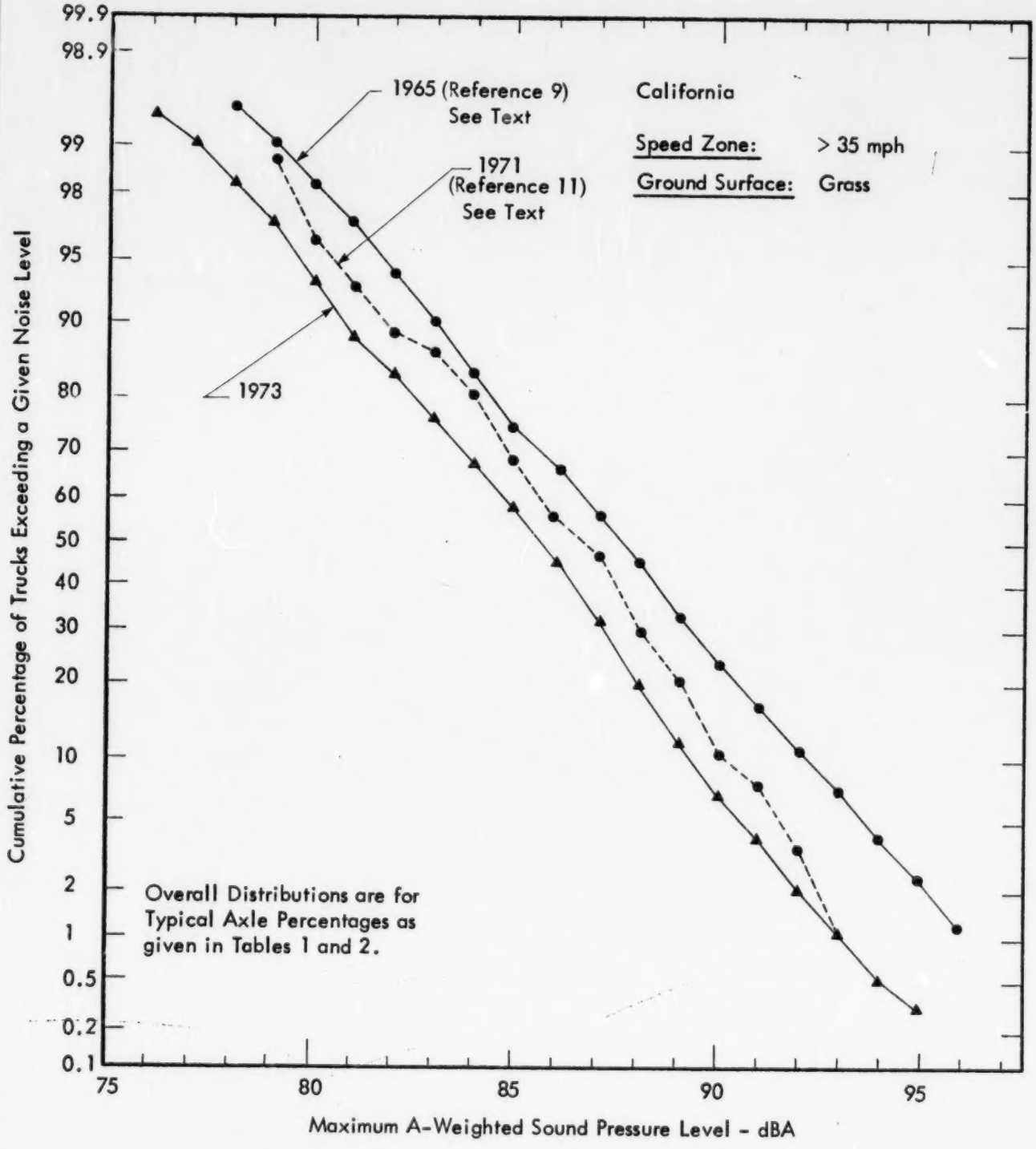

Figure 9. Overall Noise Level Distributions for Trucks Operating in Speed Zones > 35 mph in California in 1965, 1971 and 1973 Showing the Effect of Noise Regulations.

the percentage of 3-axle vehicles being equally distributed amongst both single and combination vehicles. The resulting split is therefore 80 percent combination and 20 percent single vehicles and these ratios of the original data have been combined to provide a distribution that can be compared to that measured in 1973.

The data given in Figure 9 indicate that over the period 1965 and 1973 the distribution of truck noise levels has been shifted downwards by approximately 2 to 3 decibels. This result was not necessarily expected because at first sight it might seem that the effect of a regulation prohibiting the operation of trucks with noise levels greater than a certain amount – in this case 90 dBA – together with some regulation on the sale of new vehicles would simply affect the top part of the distribution and leave the remainder fairly much the same. A check of the truck speeds involved in both measurements has shown that, if anything, the average speed has increased slightly since 1965 and, therefore, cannot be the cause of the decrease in noise level. The almost constant decrease in noise level for all trucks might indicate the use of quieter tires over the 8-year period. However, it must be remembered that many of the original violators of the California noise standards were equipped with poorly maintained exhaust systems and sometimes no mufflers at all. The addition of a muffler in these cases may well have reduced the noise level to a value well below the noise standard of 90 dBA for speed zones greater than 35 mph. Hence, the general downward trend of the complete noise level distribution.

The effect of the regulations in California can also be examined by reviewing the change in noise levels produced by trucks traveling at low speeds where the noise is produced predominantly by the propulsion system. The distribution of noise levels for trucks as measured in states without regulations in 1973 is shown in Figure 10 along with the distribution as measured in California in the same year. Here again there is a clear distinction between the two distributions, particularly at the higher noise levels. The difference at the 2-percentile level is on the order of 5 dB – an amount which is clearly distinguishable from any error in the measurement procedure. Similar measurements conducted in 1973 in the State of Colorado show a noise level distribution lying

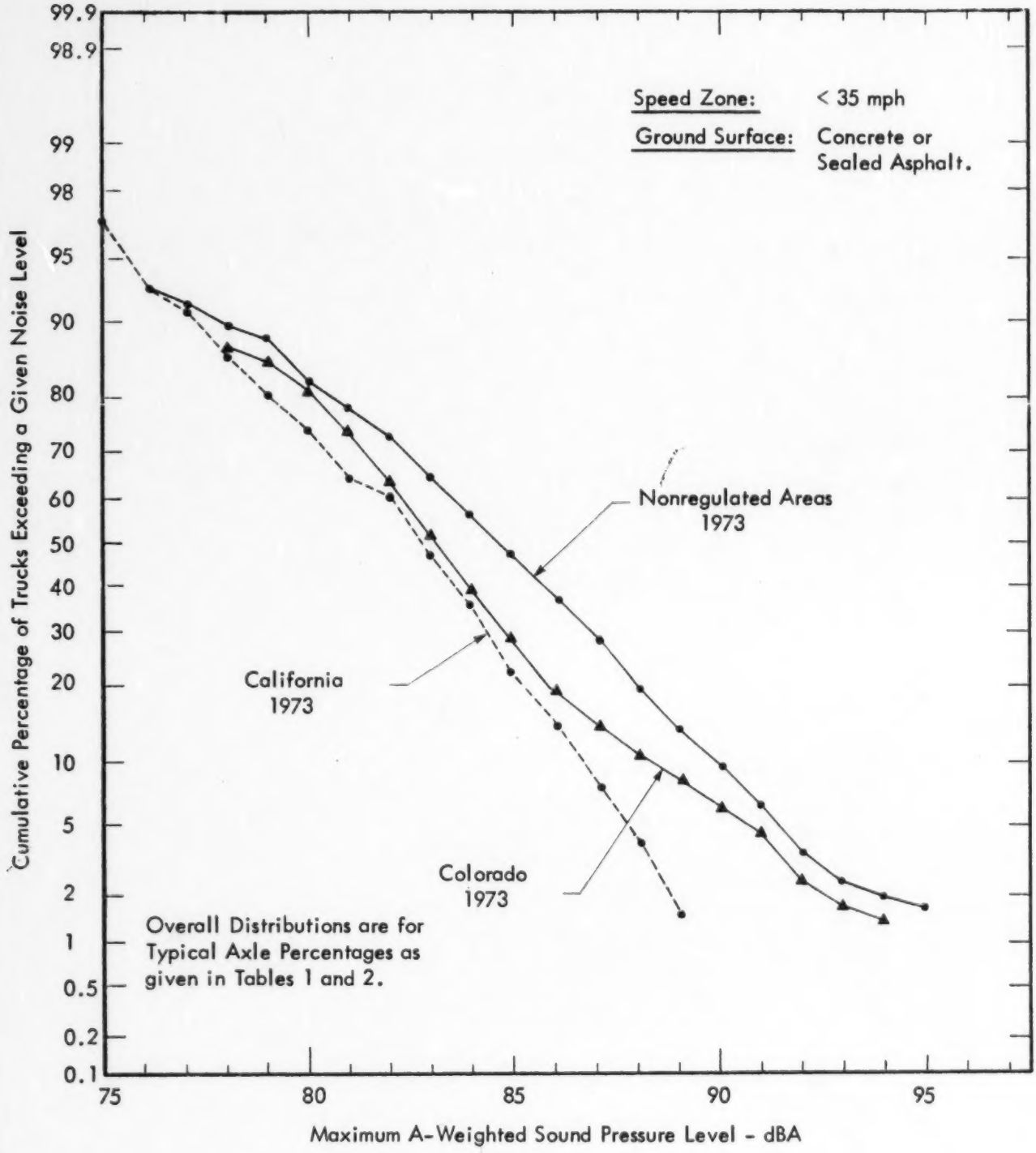

Figure 10. Overall Noise Level Distributions for Trucks Accelerating in Speed Zones < 35 mph as a Function of Regulations.

in between the others in Figure 10. The regulation in this state has not been enforced for as long nor is the enforcement as active as the corresponding one in California, and so it is to be expected that the noise levels would be slightly higher.

A rather interesting comparison of noise level distributions is shown in Figure 11 for trucks operating at freeway speeds. Again, the noise distribution for states without regulations is included together with distributions from California in 1973, but this time a comparison is made with the distribution as measured in a state close to one with active enforcement.[12] The distribution shown in Figure 11 indicates that the regulations in California have had an affect on interstate trucks operating in Washington. A major route along the Pacific Coast is Interstate 5 which, of course, passes through both California and Washington, and it might be expected that trucks operating on this route travel through both states. This effect might be termed "regulation by influence" and it has an important application in the development of an effective national enforcement program in that the enforcement of noise regulations at a limited number of points can successfully reduce noise levels over a much wider area.

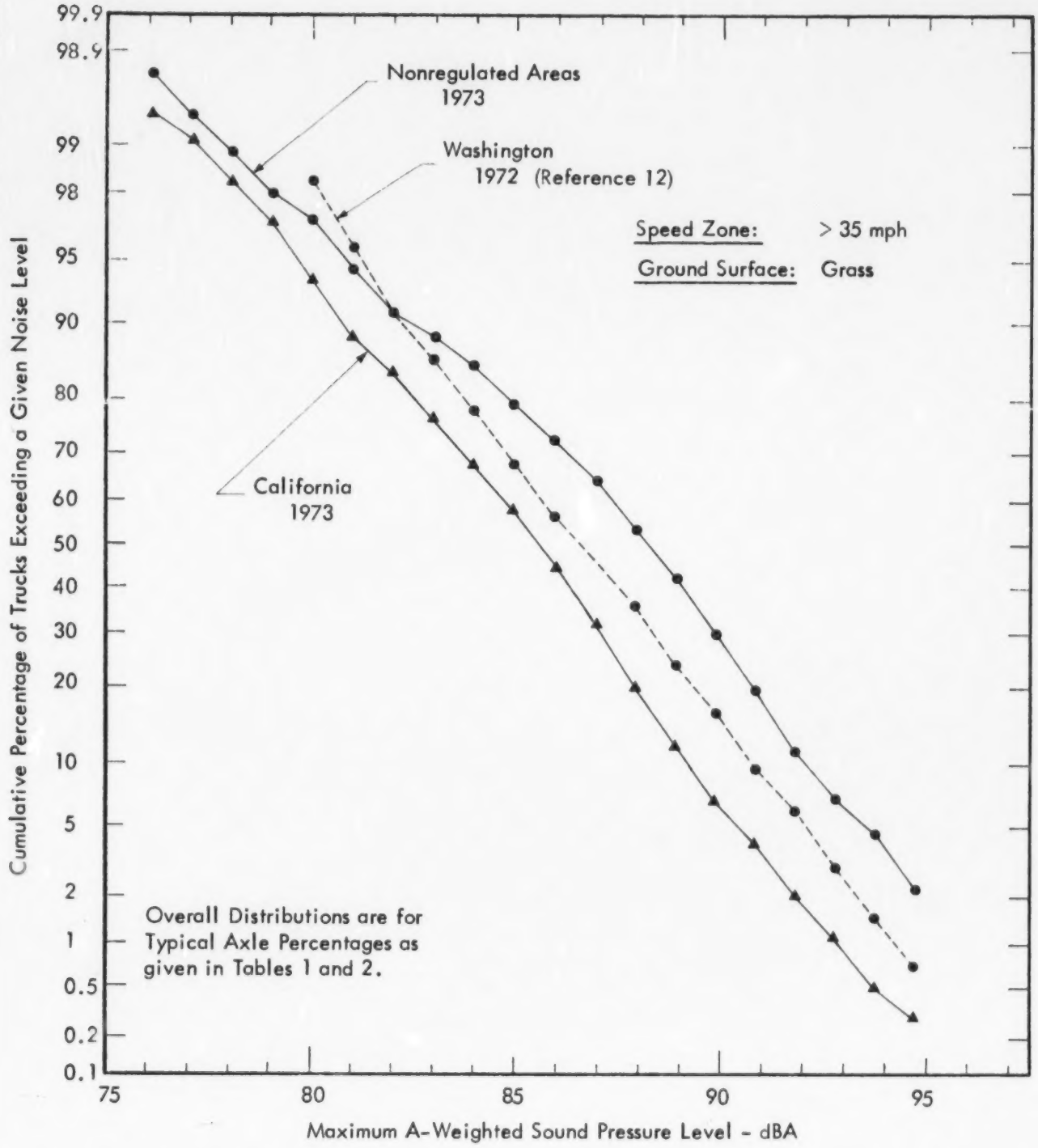

Figure 11. Overall Noise Level Distributions for Trucks Operating in Speed Zones > 35 mph Indicating the Effect of Regulation By Influence.

4.0 CONCLUSIONS

The data presented in this report were obtained from a survey of noise levels from a total of 7449 trucks operating under varied but specified conditions in different parts of the country. The results, therefore, provide a fairly detailed indication of the statistical distribution of noise levels that can be expected at highway locations with and without the introduction of local motor vehicle noise regulations. Specific conclusions from this study are discussed in this section.

The traditional method for characterizing the noise produced by trucks operating on the highway at low speed is to measure the maximum noise level as the truck accelerates past a single microphone. Because the noise level produced varies with time according to the gearshift pattern, this type of measurement procedure will normally provide a conservative estimate of the maximum noise level. It appears that this estimate is typically on the order of 1.5 dB too low, but this figure may in some cases be as great as 5 dB. Accordingly, the pass-by measurement procedure is not suitable for the strict enforcement of truck noise regulations, although it is a convenient method for identifying major violators.

This conclusion indicates that the optimum location for enforcement of low speed truck noise standards – applicable to the propulsion system – is on a grade where the vehicles are operating at maximum engine speed without changing gear. Under this condition, the pass-by measurement technique is valid. Note, however, that this approach is not normally applicable to the measurement of truck noise levels in high speed zones where the noise standards are increased to compensate for an increased contribution from the tires.

The alternative procedure for measuring low speed noise levels, namely the stationary run-up test, does not have the disadvantages of the pass-by measurement. In this test, the engine is always accelerated to maximum rated speed and so the measurement of the maximum noise level by means of a single microphone is not fortuitously dependent on the gearshift cycle. Moreover, the test is extremely repeatable, and the results correlate well with those obtained from the recommended SAE J366b procedure.

It is immediately apparent from the results that one factor which has to be considered in the development and subsequent enforcement of regulations is the effect of the ground surface alongside the highway. The difference in noise levels measured at a site with a hard ground surface – concrete or sealed asphalt – between the vehicle and the microphone, and one with a grassy surface, is on the order of 2 dB for trucks traveling at low speed.

The introduction and enforcement of noise regulations have had the effect of reducing truck noise levels in California. The reduction is due partly to regulations on the sale of new trucks, but probably more to the operational regulations that have been enforced for a number of years. It would appear that the mean noise level for a typical distribution of trucks that passes along any given highway has been reduced by about 2 dB with a significant reduction in the "tail" of the distribution, i.e., a reduction in the number of excessively noisy trucks. Furthermore, some of this reduction has been observed in nearby states in a form of "regulation by influence."

In summary, it has been shown that truck noise levels can be reduced significantly by the application and active enforcement of noise regulations. The enforcement may be even more effective, however, when applied by means of a test method – such as the stationary run-up procedure – that measures true maximum noise, rather than by the more usual pass-by measurement.

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